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Placer formation processes in the cenozoic of Northern and Eastern Kazakhstan

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ABSTRACT
The article is devoted to the generalization of data on the entire geological and genetic range of placers in Eastern and Northern Kazakhstan: from the weathering of the kaolin profile at the root sources of ore minerals Au, Ni, Co, RM, Ti, Zr, Nb, TR, through polyfacial and alluvial placers of the near demolition of the Zaisan depression to coastal-marine titanium-zirconium placers Northern Kazakhstan and Pavlodar Irtysh region. The sections and patterns of ore localization for gold- and nickel-bearing weathering crusts of the Rudny Altai are considered in more detail. An idea is given of the different conditions of formation of the Paleocene-Miocene ilmenite placers of the Zaisan Depression, depending on the tectonic regime – rifting in the Paleocene-Eocene and orogeny in the Lower Miocene. The dating of titanium-zirconium placers of the Pavlodar Irtysh region has been clarified due to the large-scale removal of silicon from the eluvium of the Kazakh shield. The relationship of the processes of coastal-marine placer formation with regional paleogeographic changes in Central Eurasia, starting with the collision of Hindustan and Eurasia and the Paleocene-Lower Eocene temperature maximum, is shown. The role of the completion of water exchange between the Tethys and Arctic shelf seas in the occurrence of constant westerly winds from the Tarim and Gobi, which played a major role in the formation of placers in the northern border of the Kazakh Shield, is shown.

Keywords: Weathering crust, titanium, rare metals, inshore placer.

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Introduction

This article is devoted to a review of the processes of placer formation that occurred from the Late Cretaceous to the Late Eocene, and their results in the form of placers of various genotypes that were widespread in the eastern part of Northern Kazakhstan and Kazakh part of Altai. In this article, we will consider the features of predominantly eluvial (Au, Ni, реже Ti и-REE) and coastal-marine (Ti, Zr, REE) placers. Special attention is paid to regional climatic factors that contributed to the enrichment of sands with heavy minerals in the coastal zone of the Middle and Upper Eocene seas, primarily to the formation of a system of coastal currents that played an important role in the formation of placers.

The territory described is located at the junction of two geostructures of the 1st order: the Kazakh Shield, in the zone of its immersion under the Cretaceous-Paleogene rocks of the West Siberian Depression, and the Altai collision-shear system, which also sinks under the loose formations of Western Siberia in a northwesterly direction (Fig. 1). The territory under consideration is characterized by the presence of a full range of placer formations, depending on the degree of connection with indigenous sources. A series of placer formations begins with metalliferous weathering crusts with minerals Au, Nb, Ta, Li, Sn, W, Ti, Zr, Ni, and Co, in some cases with epigenetic infiltration and enrichment with REE phosphates. This is followed by alluvial placers with minerals Au, Sn, W, less often Ti and TR, which are directly related to the indigenous sources. The third representative of the series is coastal-marine and lake placers with a predominance of Ti-Zr-TR in the heavy fraction.

The main sources of placer minerals were regionally developed weathering crusts on a substrate of different ages, or intermediate reservoirs, from Late Cretaceous to Early Eocene alluvial and deltaic facies. And, if the connection between the placer and the source for eluvial formations is obvious, for alluvial formations it is easily detectable, then for coastal formations it is usually not detectable due to the vastness of the drift area drained by river systems

Considering that the purpose of the article is to summarize the data obtained by the authors for many years of research on Northern and Eastern Kazakhstan placers, the results are presented in the form of a consistent description of individual deposits in a single genetic series, from eluvial metal-bearing formations and products of their migration and enrichment, to coastal-marine placers in final demolition basins.

Materials and methods

This article is the result of author's research on off-shore Ti-Zr placers and rare-metal-bearing weathering crusts, using numerous publications on mineralogy and paleogeography of North Kazakhstan, Western Siberia, Tarim and Chinese Altai. For certain areas of placer genesis in Northern and Eastern Kazakhstan, the main method of forecasting placer formations was the method of facies analysis, with the identification of various accumulative shelf forms of Eocene seas, paleoroussels, delta channels, etc. The methods of material analysis are widely used, first of all, the granulometry of ore and non-ore sands, the results of which were published earlier [[1], [2]] and are summarized in this paper (Table 1), in comparison with Ti-Zr placers of other areas and other age levels. Data on the fractional composition of the Druzhba deposit Eocene sands in Pavlodar Irtysh, Obukhovsky and other placers in Northern Kazakhstan, served as a starting point for recognizing the conditions of formation of the main ore bodies as shelf, in contrast to modern coastal-marine placers formed mainly on beaches. Such interpretations determine the possibility of finding new ore bodies south of known deposits zone, as discussed in more detail below.

The Altai Hercynid is characterized by a system of parallel structural zones extending to the northwest (Rudno-Altaiskaya, Irtyshskaya, Kalba-Narymskaya, Charskaya and Zharma-Saurskaya), which differ in geodynamic evolution, geology and metallogeny and are separated by deep faults (fig 2). Large-scale magmatism appeared in Eastern Kazakhstan in the Late Carboniferous-Late Permian period, i.e. at the post-orogenic stage. The orogenic stage was invaded by sub-alkaline gabbro and large granitoid massifs [[3], [4]], including monzonites and biotite-amphibole granites of the multiphase Karaotkel-Preobrazhenskaya intrusion, dated 290 ± 2 million years ago, and which was the source of eluvial and alluvial placers ilmenite known as Karaotkel and Satpayevskoye deposits [[3], [5]].

The period of active orogeny was followed by a stage of relative tectonic quiescence, with relief alignment and rifting, resulting in the formation of the Zaisan Depression, between the Altai Hercynides and the Chingiz-Tarbagatai caledonides [[6], [7]].

In the Late Cretaceous, under conditions of relative tectonic rest, a crust of weathering of a humid profile was formed on the formations of the Paleozoic and Mesozoic.

Figure 1 - Study area location map

The upper age limit of the weathering crust dates back to fairly well-faunistically characterized deposits of the Danish stage in the Semipalatinsk Irtysh region [[8], [9]]. To the west, in the Pavlodar Irtysh region, marine formations of the Middle and Upper Eocene lie on the weathering crust formations with a clear angular discrepancy [[2], [9], [10], [11]].

Eluvial formations are known in depressions inherited by river valleys and in rare remnants of peneplene, usually developed on effusions of medium-basic composition and in crumpling zones formed by ophiolite complexes (Ekibastuz-Shidertinsky and Charsky belts) in the small-scale area of the Kazakh Shield. In the areas of transition of the Kazakh upland to the plains of Western Siberia, weathering crusts are preserved in depressions of the Paleozoic basement and in the bases of scarcely pronounced ledges in the modern relief tracing the stepwise immersion of the Paleozoic basement under the cover of Cenozoic formations of the West Siberian Depression.

In the areas of the Rudny Altai low mountains, eluvial formations are represented by fragments of foam in the interfluves, usually in the altitude range 450-650 m [[12], [13], [14]]. Significant areas of alignment surfaces in the watershed spaces are characterized by incompleteness of the eluvium section due to later erosion, when only zones of disintegration and clay-sand-gravel formations are represented. Less often, there are fairly complete sections, with 20-30 meters or more of eluvium thickness, with an exposure of complete kaolinite, kaolinite-mica and gravel-gravelly types of section. Most often, such situations occur at the junctions of faults of different orders, along zones of crumpling, fracturing, and other superimposed endogenous processes leading to the disintegration of the source. rocks. Known deposits of gold and rare metals are confined to such zones [[7][15], [16], [17], [18]].

The distribution of weathering crusts and their processed products in the form of placers of various genotypes is shown in Fig. 3. The areas of eluvium are taken into account in the case of clay neoplasms typical of hypergenic conditions. If only the gravelly and gravelly part of the profile is preserved in the section, such an area was not shown.

In the humid subtropical climate of the Upper Cretaceous-Lower Eocene, different types of weathering crusts were formed from Paleozoic and older rocks. In the Charsky and Ekibastuz-Shidertinsky belts, Ni-Co weathering crusts of the nontronite type were formed from serpentinized hyperbasites, and gold-bearing kaolinite-mica crusts were formed from greysens and veins and other metasomatites in the Semipalatinsk Irtysh region at the Suzdalskoye, Mukur, Sekisovskoye, Mirage, and others deposits [[7], [15], [19]]. In the Kalba-Narym granite belt, alkaline and subalkaline granites of late collisional stages, pegmatites and aplites, have developed weathering crusts of kaolinite profile with Zr, Sn, W, TR, Be, Ta, Li [[7], [19]].

The Cimmerian cycle was generally destructive. Huge masses of loose material, along with scattered ore matter, were carried down into the Kulundinsk and Zaisan depressions, the West Siberian Lowland and into shallow intermountain depressions, which contributed to the formation of placers of gold, cassiterite, wolframite, monazite and other minerals.

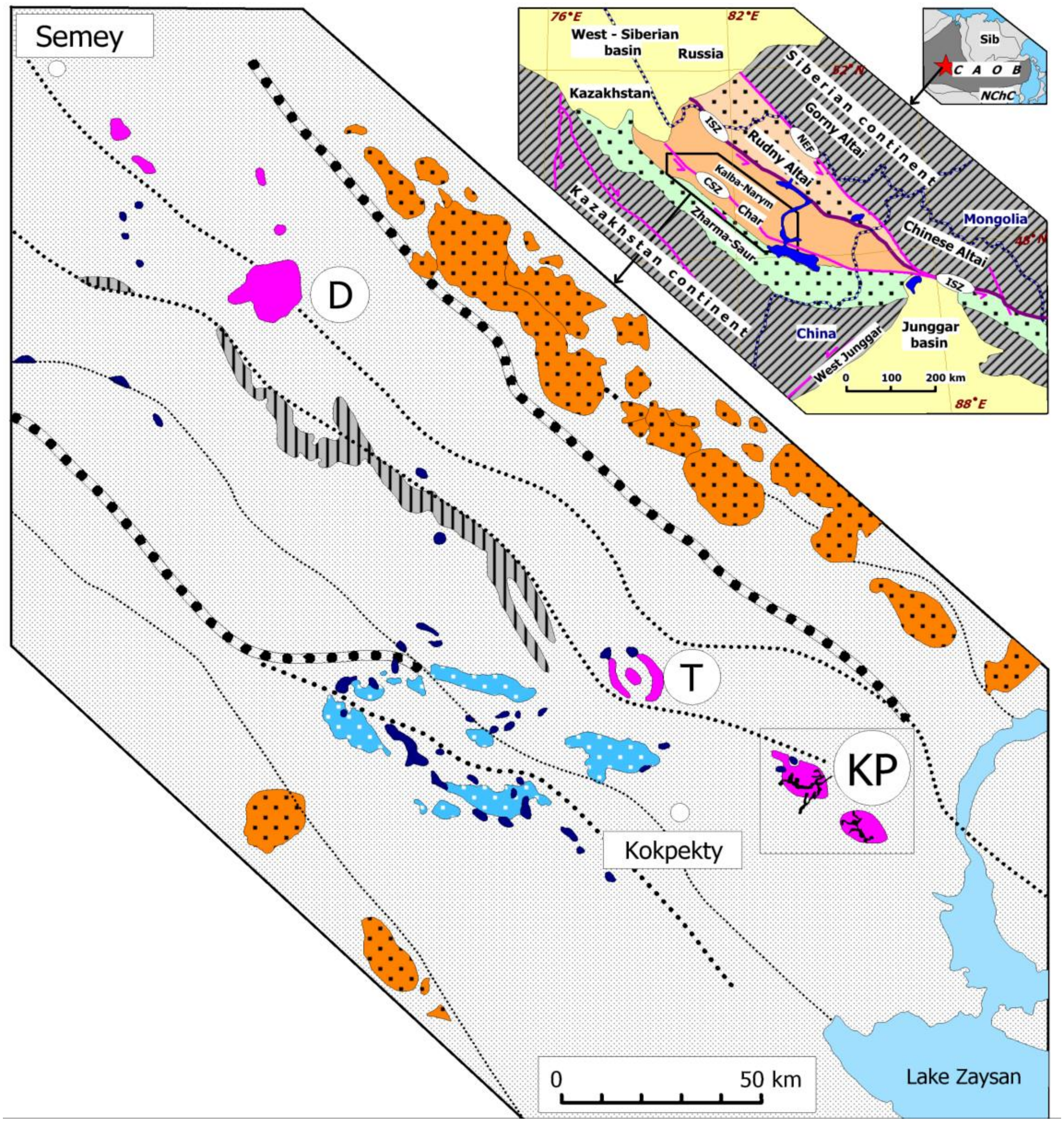


Figure 2 - Scheme of magmatic formations within the Char zone, modified after [3]. 1 - sedimentary structural and compositional complexes, 2 - Char ophiolite belt, 3 - massifs of granitoids P1, undivided, 4 - andesite-basalt series (C2-P1), 5 - massifs of subalkaline gabbro and picrite gabbro - granitoid intrusions: D -, 6 - Delbegetey, T - Tastau, KP - Karaotkel- Preobrazhenka massifs, 7 – faults, 8 - Ti-Zr placers

The eluvial complexes are formed by the initial ore zones of deposits of nickel, gold, titanium and rare metals. The processes of hypergenesis played the role of relative enrichment, due to the decomposition and removal of a significant mass of rock-forming minerals. At the same time, hydration, hydrolysis, and oxidation during hypergenesis at latitudes corresponding to Northern and Eastern Kazakhstan in the Cretaceous-Lower Eocene, led to a kaolinite or kaolinite-hydromica profile of the weathering crust. Laterite profiles of eluvial formations are known in the Turgai trough, and in isolated areas of the northern slope of the Kazakh Shield, where geomorphological conditions of crust formation contributed to deep washing of elevated parts of the foam, with lateritization of products [10]. But these regions are outside the research area.

An example of a gold deposit where residual weathering crusts are considered as a separate enrichment object is the Suzdal deposit (Fig. 4). The indigenous mineralization is confined to mineralized zones of quartz-carbonate-sulfide composition localized in carbonate-terrigenous deposits of the lower-middle Vis. The gold in the bedrock is concentrated in arsenopyrite, pyrite, pyrrhotite, and chalcopyrite.

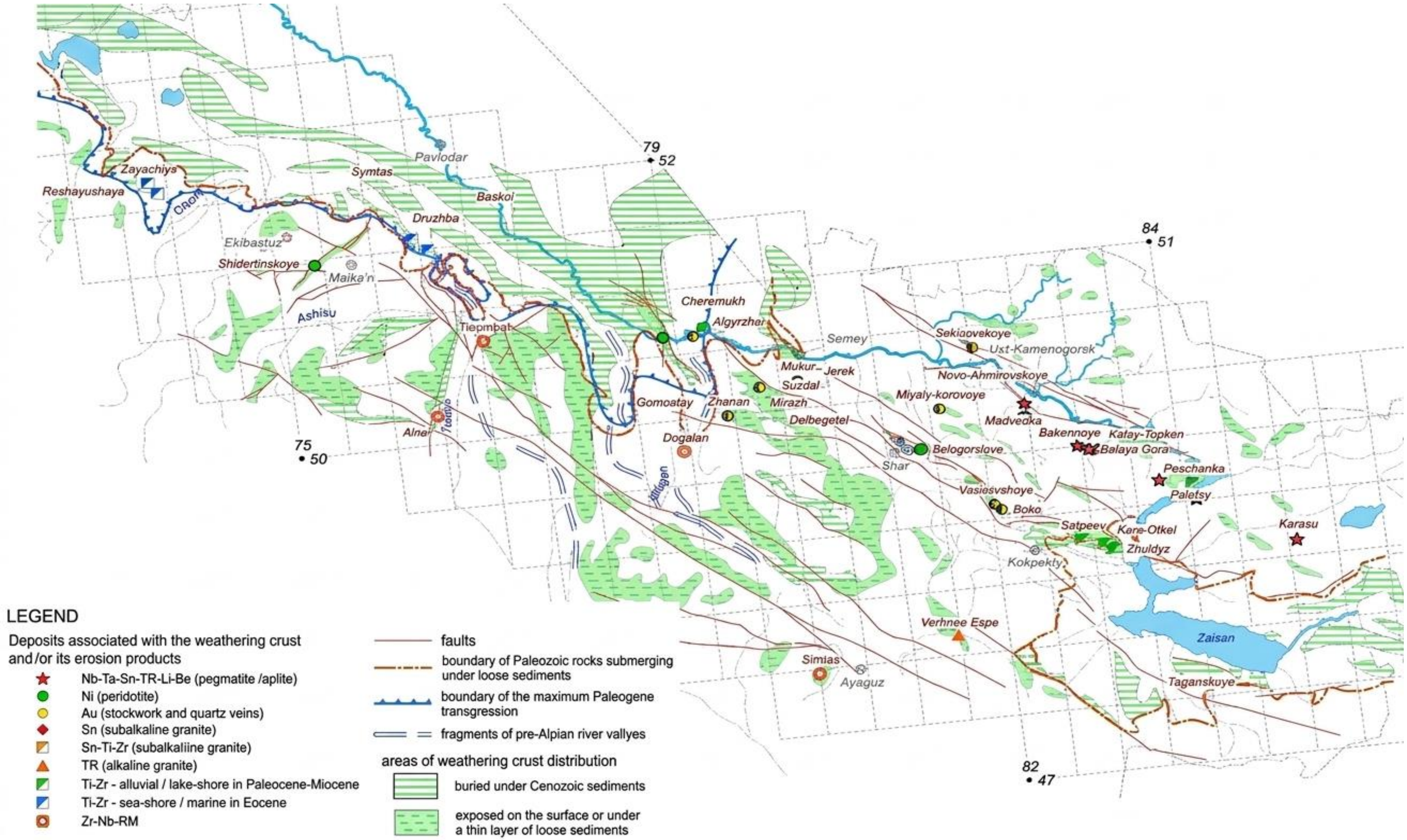


Figure 3 - The spread of ore-bearing weathering crust and their redeposition products. Based on the author's materials, using data from [11], [15], [19], [20], [21], [22].

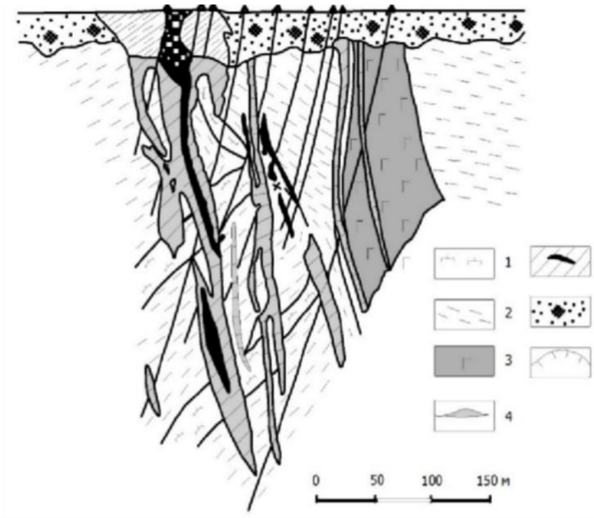


Figure 4 - A section through the ore zones of the Suzdal gold deposit, according to [15].
1, 2 – Lower carboniferous terrigenous-carbonate (1) and siltstone-sandstone (2) formations, 3 – lower-middle carboniferous gabbro-diabases, 4 – upper carboniferous dikes of acid composition, 5 – linear and linear-areal weathering crusts, 6 – cover loams and sands, 7 – carrier border line

The deposit has developed a linear and linear-area type weathering crust with a thickness of up to 80 m and a typical section, according to [[15], [18]]:

1. Variegated eluvium containing up to 50% kaolinite, 10-20% mixed-layer minerals and montmorillonite.
2. Structural eluvium of kaolinite-hydro-micaceous composition, with siliceous-goethite veins.
3. A sandstone in a clay aggregate (up to 40% clay of a hydro-micaceous composition) with a well-preserved structure of the initial rocks. Hydrogetite and hydrohematite accumulations and deposits of manganese hydroxides are characteristic.

A characteristic feature of the hypergenesis of the kaolinite stage in gold deposits, where it is associated with sulfides and has a clear correlation with SiO2 and As, the authors [[18], [23]] consider the formation of high-grade hypergenic gold due to large-scale dissolution of gold-bearing minerals (arsenopyrite, pyrite, etc.), local redistribution along the weathering crust profile, and redeposition under oxidative conditions, which is accompanied by an increase in the size of native gold towards the upper horizons of the weathering crust.

Nickel–bearing weathering crusts are known from the Gornostaevskoye and Belogorskoye deposits in the Charsky hyperbasite belt, and the Shidertinskoye deposits in the Ekibastuz-Shidertinsky belt. An example is the Belogorskoye deposit, where ore nontronites are mined on an industrial scale.

The main ore deposits of the Belogorskoye deposit (Fig. 5) are concentrated in the fractured linear type of the weathering crust of serpentinites, listvenites and metasomatic quartzites. Three separated deposits of nickel ores have been identified and contoured at the deposit. The ores are mostly of the silicate type, but there is also nickel sulfide mineralization of a non-industrial nature, spatially and probably genetically related to larch rocks [24].

A wide development of nontronite eluvium with an average thickness of 8.5 m has been revealed on the deposit area, where the main ore minerals are nontronite, kerolite, psilomelan, asbolan and magnesite, with a Ni content of 0.5-6.8%. Concentrations of Au, Ag, Sb and weight samples of Pt, Pd, Hf were revealed [24] in ochreous eluvial formations, which indicates a potential expansion of the spectrum of ore components of the weathering crust according to the hyperbasites of Eastern Kazakhstan.

Somewhat apart from the above-mentioned deposits of the weathering crust is titanium-rare metal-feldspar deposit Kara-Otkel, which is a two-tiered eluvial (in the lower part) and alluvial-proluvial (in the upper part of section) placer.

Alluvial titanium deposits are known worldwide (Ariadnenskoye deposit in Far East, RF, Appalachian River placers, US, intracontinental placers in India, sites in Mozambique and Madagascar) and, in general, have low industrial value [[1], [22]] due to low concentrations of industrial minerals and small placer sizes. The industrial value of individual objects may increase due to the peculiarities of mineralization (rare-metal minerals, tin or gold as related metals, or ceramic feldspar, like Kara-Otkel).

The Kara-Otkel deposit consists of several placers of three age generations [[5], [13], [25]] with a complex fan-shaped morphology of valleys. Placers of a two-tiered structure, where the lower tier was formed in the Late Cretaceous weathering profile with a predominance of kaolin, the upper tier in the sediments of the North Zaisan Paleogene formation (Fig. 6).

The Karaotkel placer deposit is confined to a horseshoe-shaped depression, open to the southeast, closed on three sides along the periphery by a low shaft, clearly expressed in the modern relief and confined to the contact of the multiphase Karaotkel-Preobrazhenskaya intrusion with sedimentary rocks of the lower Carboniferous Serpukhov stage and the Bukon formation of the Middle Carboniferous.

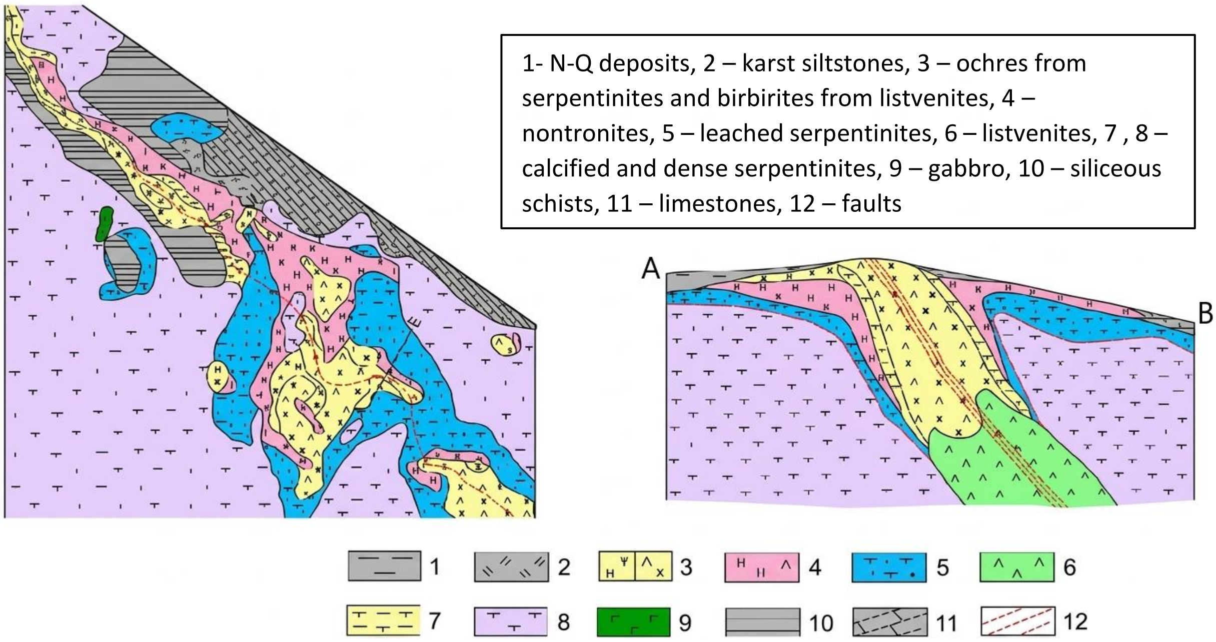


Figure 5 - Geological diagram of the Belogorskoye field and generalized section along the A-B line

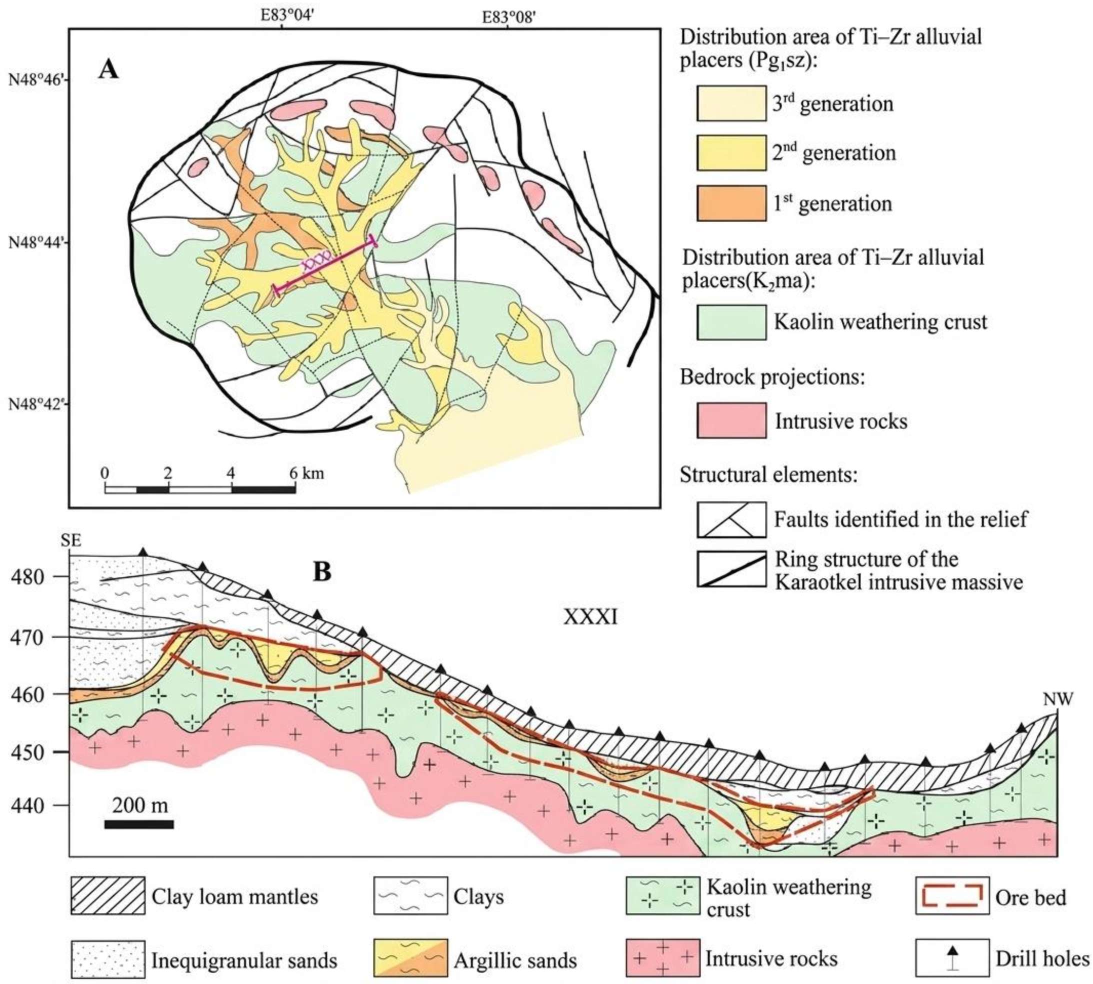


Figure 6 - Geological and structural sketch of the Kara-Otkel deposit, according to [5]

Several main channels with a width of 1-1.6 km and a length of up to 12 km are known in the field. The tributaries are 0.3 to 0.6 km wide and 1-3 km long. The thickness of the productive deposit is up to 14 m, on average it is 4-7 m.

The lower part of the ore section of the deposit is confined to the weathering crust of gabbro, diorites, granosienites and more alkaline differences in acid magmatism. The upper subzone of the kaolin-type weathering crust (thickness from 2-3 to 8 m) is represented by loams with rounded uneven patches of brownish-red calcification. In the lower parts of the subzone, the clay component is 50- 70% hydrous, kaolinite – up to 15%, in the upper parts - the content of hydrous varies between 20- 30%, kaolinite – 40-50%. The composition of loams contains 55% siltstone-clay fractions, and 45% - sandy. Macroscopically, the lower part of the ore section is made of variegated and light sandy clays and loams, the ore component is represented by ilmenite, in the form of uniform inclusions and sharply enriched nests and interlayers, with a content of up to 4-15%.

The upper part of the ore section in the main channel is represented by unevenly granular arkose obliquely layered sands of the North Zaisan formation [5], consisting of quartz (12-48%), potassium feldspar (5-30%), plagioclase - up to 7%, fragments of kaolinized sandstones and siltstones of the lower and Middle Carboniferous (up to 15%), with inclusions ilmenite and zircon.

Ore minerals represented by ilmenite, zircon, leucoxene, and rutile undergo the following changes in composition and appearance:

- ilmenite: average contents in the weathering crust of 1.72%, in the sands of the North Zaisan formation - 2.96%, zircon: in the weathering crust – 0.15%, in the sands – 0.6%, leucoxene – 0.63% in the weathering crust, 0.46% in the sands.

Ilmenite and zircon experience obvious enrichment in alluvial-proluvial conditions, the leucoxene content decreases, apparently due to the low mechanical strength of the grains. In terms of the chemical composition of ilmenite, as the initial ore–bearing formations matured, the bedrock – the crust of chemical weathering - the products of the redeposition of the weathering crust accumulated titanium oxide with the loss of total iron [5]. Judging by the geological position of the deposit (Fig.7), the root sources of the placer ore minerals appear to be quite clear. Studies of the composition of ilmenite and zircon from the Karaotkel-Preobrazhenskaya intrusion, eluvium and redeposition products performed by one of the authors of the article indicate that the chemical composition of ilmenite from the weathering crust and Paleogene sands has a similar composition to the indigenous intrusive rocks of four of the five phases of the Karaotkel-Preobrazhenskaya intrusion, with the lowest discrepancies in the content of basic elements (TiO2 and FeO) between ilmenite from gabbro of the 4th phase, weathering crust and Paleogene sands [13].

The Satpayevskoye titanium deposit, located 18 km north of Kara Otkel, is confined to the zone of transition from an accumulative plain to a low mountain and is localized in alluvial deposits of the Aral formation of the Miocene, lying with a sharp angular discrepancy on the surface of Paleozoic rocks or their weathering crusts.

The mineralization plan has a ribbon-like elongated shape, with maximum thickness in the central part with a gradual decrease towards the flanks. The areas of alluvial mineralization in the plan follow the contours of the faults, which are manifested in the form of crushing zones, intense fracturing and linear weathering crusts (Fig. 8). The beds of Neogene watercourses clearly inherit fragments of discontinuous tectonics. There are 5 placer sites in the field with a similar geological structure, with valleys ranging from 8.7 to 12.6 km long and widths from the first hundred to 900 m. The thickness of the ore sands is from 1 to 14.8 m.

Ilmenite mineralization is concentrated in sandy clays and in poorly sorted medium- and multigrained, often clay sands. The fraction content of -0.05 mm is from 13 to 84%, with a kaolinite-hydrous composition. Sand fractions are represented by quartz (60%), potassium feldspar, and oxides- iron hydroxides. Ilmenite occurs in the form of poorly and moderately rounded grains, flat and tabular precipitates and their fragments. Zircon is found in insignificant concentrations, which determines the specialization of the deposit as purely titanium. A comparison of the ilmenite placers of the Satpayevsky deposit and the Preobrazhenskaya intrusion [[13], [26]], as well as the structural position of the Satpayevsky ore field along the boundary of the intrusion and zones of tectonic disturbances inherited by placer watercourses, indicates that the Preobrazhenskaya intrusion served as a source of placer ore material.

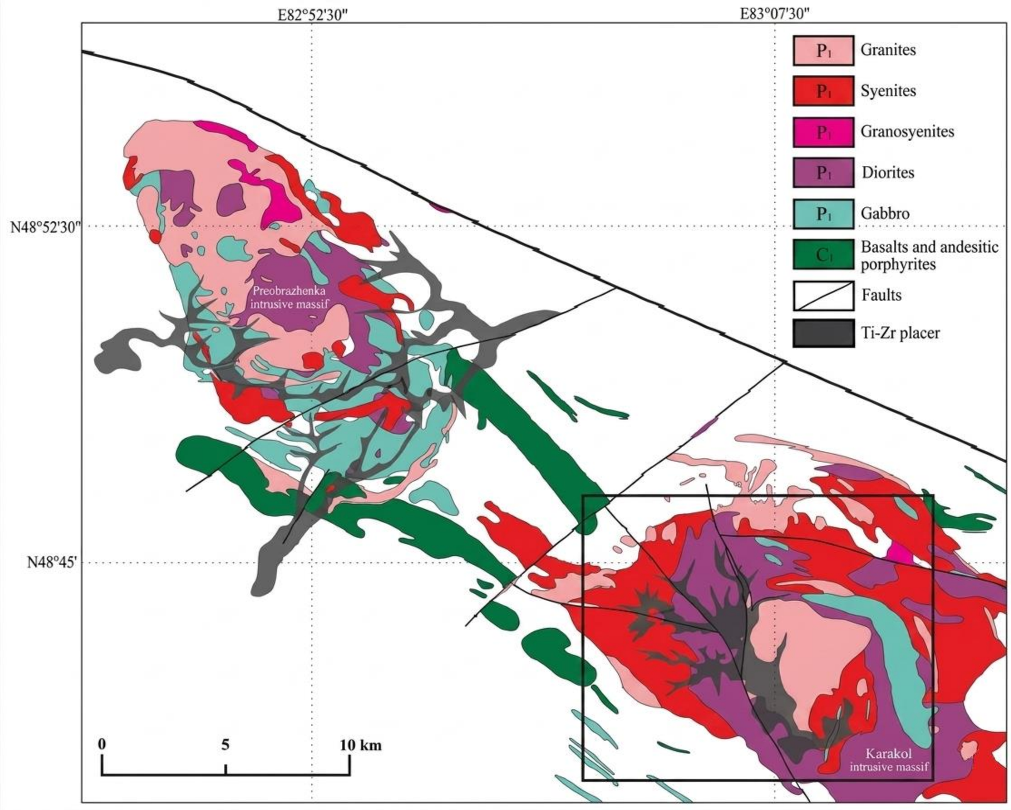
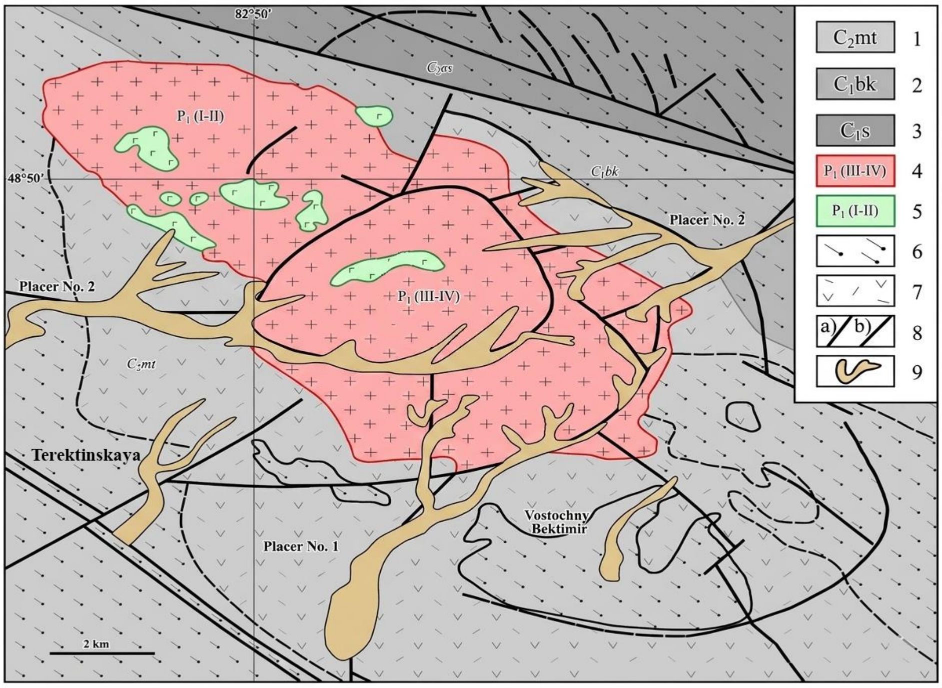


Figure 7 - Geological map of the Karaotkel-Preobrazhenskaya multiphase intrusion, by [[3], [4], [5]]



1 - Maityuba suite, volcanomictic sandstone and tuff, 2- Bukon suite, interbedding of clayey, argillaceous aleurolite, 3- visean suite, polymoctic calcareous sandstone, siltstone, shale, covers of lava and tuff, 4- Delbegetei complex, alkaline granite, syenite, granosyenite, 5- Maksut complex, gabbro, gabbro-norite, diorite, monzonite, 6- Siltstone, sandstone, shale, 7- Lava, tuff of andesite porphyrite, 8 – Deep faults, regional established (a) or proposed (b), 9 - Ti-Zr placers

Figure 8 - Geological scheme of the Satpayev Deposit of Ti-Zr placers, according to [26]

In the vertical section, the ore-bearing horizon demonstrates a transgressive cycle of the Early Miocene [[26], [27], [28]], beginning with alluvial-proluvial quartz-feldspar sand with gravel, less often sandstone and sand-gravel material. Above the section there are sandy-clay deposits, which are alluvial according to the conditions of formation. The thickness of productive sediments ranges from 2.4 to 15.6 m, with an average of 7.8 m (Fig. 9).

Industrial ilmenite mineralization is confined to the lower sandy part of the Aral formation, with a mineral content of 20-200 (120 on average) kg/m3. Clays deposited on the sands of the ore- bearing horizon contain only rare inclusions of very fine ilmenite and form the off-balance sheet part of the deposit's reserves [29].

In general, the geological and genetic position of the two described deposits in the north-west of the Zaisan depression differs in the features of ore material mobilization. In both cases, the formation of placers is associated with the redeposition of the crust by chemical weathering. However, in the case of the Kara-Otkel, the Paleocene-Eocene saw the beginning of deflection of the Zaisan Depression with weak tectonic movements of the Altai peneplain, which led to the initial stage of erosion of the Cretaceous weathering crusts [[27], [29]]. The area of the Satpayevsky deposit in the Paleocene-Eocene remained a weakly hilly peneplenized plain.

The beginning of the Alpine orogeny at the end of the Lower Miocene is associated with the involvement of the Satpayevsky deposit area in differentiated tectonic movements. At the same time, a wide lacustrine transgression of Zaisan develops in a northwesterly direction [[13], [25], [27]], forming the lower (balanced) sand-gravel horizon of the deposit's placers. The stabilization of the erosion base, at the maximum of lake transgression in the Middle Miocene, is associated with the formation of sandy-clay formations forming the upper (off-balance) ore horizon.

Placer genesis in the Quaternary period is associated with the erosion of Paleozoic formations, which were poorly affected by the hypergenic effect, since the main part of the eluvium was recycled at the beginning of the Alpine movements. This determined the polymictic composition of the clastic material of quaternary placers of gold and rare metals in the river valleys of the Kalba-Narym zone.

The next region with Cenozoic placer generation is the northern slope of the Kazakh Shield. The formation of the Middle-Upper Eocene coastal-marine titanium-zirconium placers is known here, traced as an intermittent strip of fine-grained sands for about 400 km, from the northern slope of the Kokshetau massif to the Irtysh Valley. There are known some placer deposits, from west to east: Obukhovskaya Group (Ti-Zr-TR), Orlinogorskoye (Ti-Zr-Sn), Kara-Agash, Letovochnoye (Ti-Zr), Zayachye, (Ti-Zr), Druzhba (Zr-Ti).

These deposits have a complex titanium-rare metal specialization, with an ilmenite-to-zircon ratio of 2-3:1. The last of these placers, Druzhba– is characterized by a predominance of zircon in the heavy fraction, with an ilmenite/zircon ratio of 1:2-2.5 [[2], [10], [30]], which reflects the zirconium-rare metal specialization of the indigenous sources – sub-alkaline and alkaline collisional granites south and southeast of the placer (Fig. 10, 11).

All Eocene placer complexes of Northern Kazakhstan and the Pavlodar Irtysh region are united under the name of the Obukhov strata and are characterized by a three-member structure.

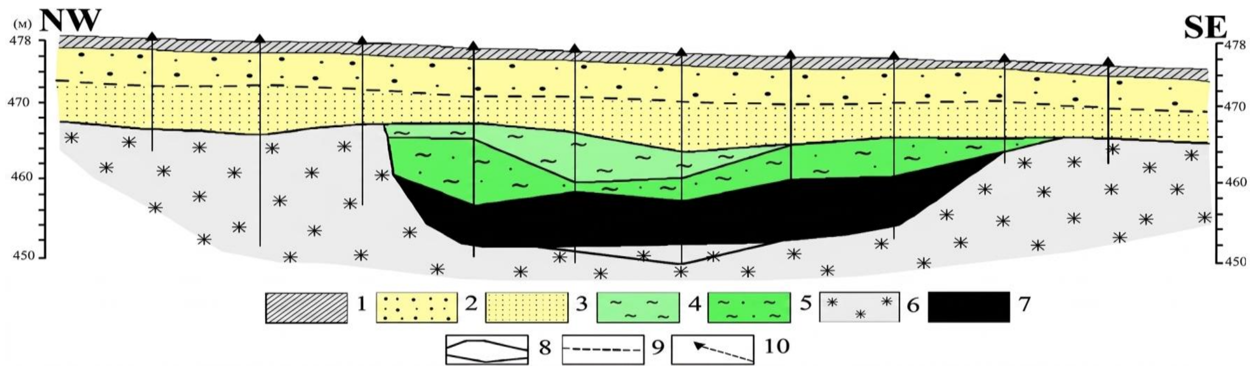


Figure 9 - Geologic al section of Satpayevskoye Deposit along the A-A line, pic. 1 – Quaternary sediments, sandy loams (QIII- IV); 2 – sandy-gravel-pebble deposits, and 3 – sands (QI); 4 – Aral formation, N 1-2, clays; 5 – sandy clays containing subeconomic ores; 6 – weathering crusts from sedimentary rocks of the Bukon formation (C2); 7– economic ore; 8 – contour of the ore-bearing zone; 9 – static groundwater level; 10 – exploration drillholes

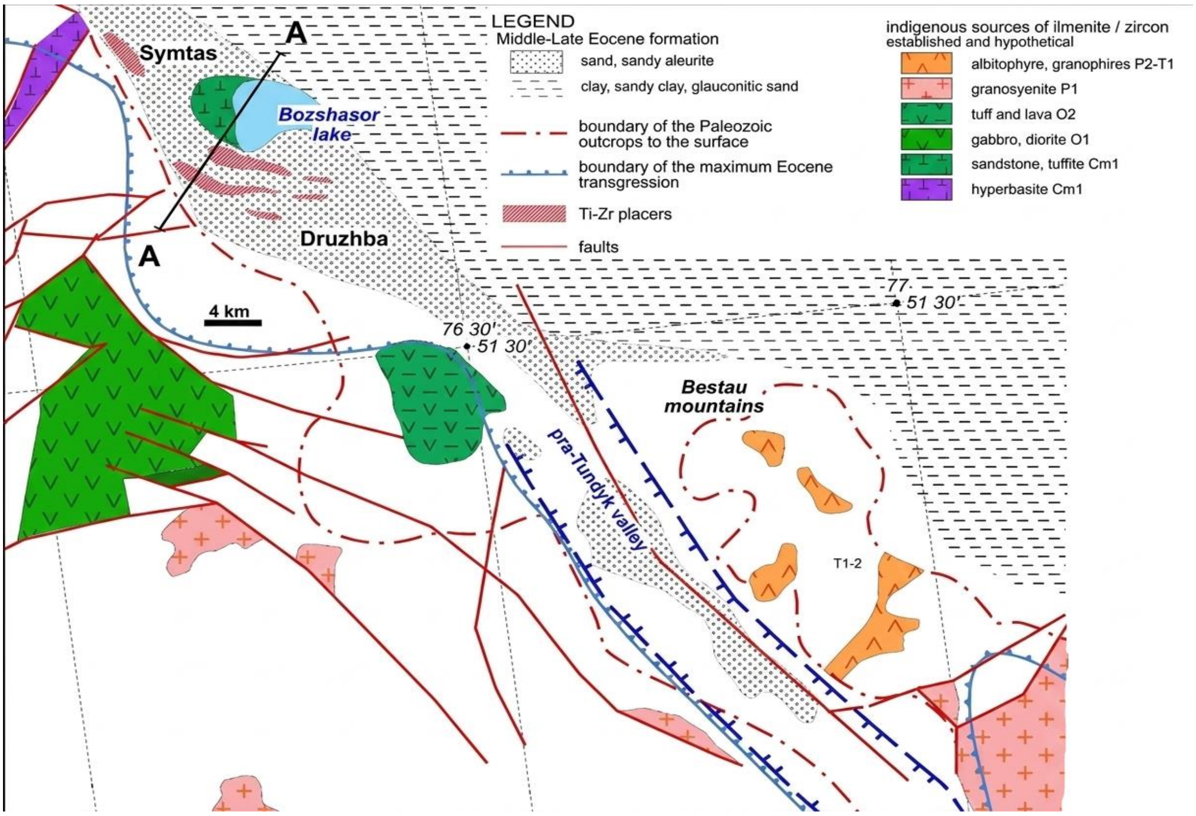
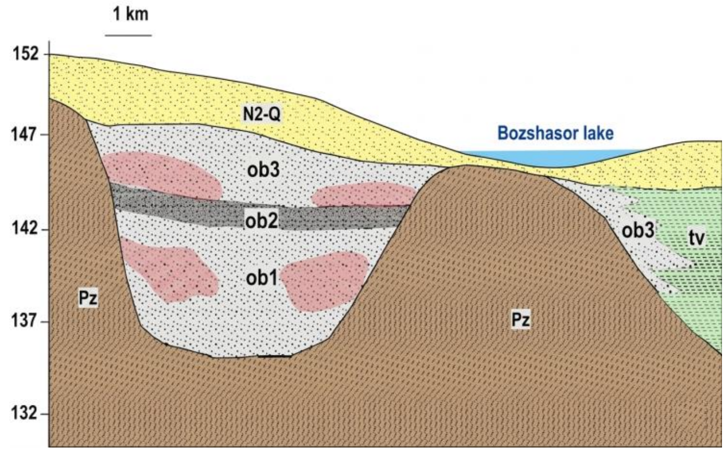


Figure 10 - Geological scheme of the Druzhba placer area showing probable sources of ore material



Pz – Paleozoic formations (without separation),
tv – clays of the Lyulinvor formation of the Middle-Upper Eocene,
ob1, ob2, ob3 –sediments of the Obukhov strata of the Middle-Upper Eocene, along the horizons: 1 – lower, 2- middle (false raft), 3- upper,
N2-Q – cover loams and clays.

Figure 11 - Druzhba generalized section along the A-A line on fig. 10

The ob1 horizon with a thickness of 2-15 m lies directly on Paleozoic formations, less often on their weathering crust, consists of fine–grained gray or greenish-gray quartz sands with a characteristic admixture of glauconite and spicules of three-ray sponges, in rare cases shark teeth are found.

These deposits are paralleled with the maximum Paleogene transgression in the Middle Eocene, corresponding to the middle part of Lyulinvor formation of Western Siberia [[2], [13], [31], [32]]. Ob1 ores are represented by ore minerals dispersed in the total thickness, without concentrations in the form of black sludge layers. The texture of the sands is indistinctly layered, often with a slightly pronounced horizontal layering formed by thin (up to 1-2 cm) layers of larger sands. Above, with a sharp transition, there are large sands of the ob2 horizon with a thickness of 1- 2 m, carrying insignificant concentrations of heavy sludge – 1-3 kg/ton.

The ob3 horizon contains the main mineralization on all placers of the northern slope of the Kazakh Shield, lying directly on the clays or coarse sands of the false raft. It is represented by fine- grained yellow, gray-yellow sands with scattered well-rounded gravel and a content of siltstone particles of up to 25% [2]. The texture of ob3 sands is emphasized by gently undulating and subhorizontal-wavy, undulating layers of slurry. The concentrations of ore minerals are in the range of 5-65 kg/t of the heavy fraction, 90% represented by ore minerals of titanium and zirconium, with a ratio of zircon to ilmenite of 2-2.5:1.

The genetic features of the Druzhba placer [[1], [32]], which distinguish it from other deposits of the northern slope of the Kazakh Shield, consist, as already noted above, in:

1- Zircon ore specialization,

2- the sand-gravel composition of the false raft, in contrast to the clay composition of the other placers,

3- very fine-grained composition of ore-bearing horizons and ore minerals.

The zircon specialization of the placer is explained by the widespread development of subalkaline and alkaline granite intrusions, which are characterized by zirconium-rare metal mineralization in the southern and SE fringes of the placer. Ore minerals were brought by the river (Pra-Tundyk), which drained the areas of development of zircon-bearing granites with a developed weathering crust.

The rough composition of the false raft, unlike the clay composition of other deposits, is explained by the deflection of the Irtysh syneclise inherited from the beginning of the Eocene, which was reflected in the deep depression of the Middle Eocene Sea, with penetration into the valley of the Great Tundyk by 40-50 km. This fact is justified by the presence of well-rounded sands cemented into quartzite-like sandstones with leaf prints of the Middle-Upper Eocene flora [[32], [34], [35], [36]].

The zircon source was Late Carboniferous and Early Permian granosienite massifs drained by the Great Tundyk (Bestau, Kalmak-Kurgan, etc.), the distance to which is 40-100 km. Zircon-malacons of the Early Triassic liparite-dacite Bestau massif (Fig. 10), despite the significant content of zircon in rocks (up to 1.5%) and the relatively short distance to the Druzhba placer, took little part in the formation of zircon concentrations [[2], [32]]. This fact is explained both by the low resistance of the malacons themselves to river and coastal-marine transport, and by the characteristic western direction of longshore transport from river deltas, as the main suppliers of placer material, whereas the Bestau massif is located east of Tundyk delta. The western direction of transfer has been reliably diagnosed in the Obukhov placer group, Zayachye, and Druzhba [[1], [2], [22], [28]].

A characteristic difference between the material composition of Druzhba and other placers of the northern slope of the Kazakh Shield and, especially, Western Siberia, is the extremely small size of ore minerals and the corresponding quartz grains in hydraulic size [[32], [36]]. Ore minerals of titanium-zirconium placers in Western Siberia have the dimension of fine-grained sand up to the upper boundary of coarse siltstone, Druzhba - the dimension of coarse siltstone (55%) and fine siltstone and pelite (45%), Table 1.

Table 1 - The dimension of heavy fraction minerals from Sublittoral and Alluvial Cenozoic placers in Northern Kazakhstan, southern part of West Siberia, Zaisan Depression, and modern placers. According to the [[2], [13], [22], [30], [33]]

Ti-Zr minerals dimension, mm	Modern placers (Aynemer & Konshin, 1982)	Zaisan *Early Miocene*	North Kazakhstan and Pavlodar-Irtysh *Middle-Late Eocene*		South of West Siberia (Rikhvanov et al., 2001) *Early Oligocene*	
		Satpayevskoe	Obukhovskaya	Druzhba	Tuganskaya	Tarskaya
+1.0		0	0	0	0	0
-1.0+0.5	0.3	0	0	0	4.6	1.2
-0.5+0.25	2.5	3.5	0.8	1.0	5.1	1.9
-0.25+0.1	60.1	20.9	5.7	3.3	44	12.2
-0.1+0.05	30.1	60.8	52.9	50.1	29	51
-0.05+0.01	5.2	13.8	23.3	25.1	2.6	16.5
-0.01	1.4	1.0	16.5	20.3	14	14.4

So, modern placers are concentrated in medium-grained beach sands with fine and medium-grained dimensions of ore minerals. Placers of Western Siberia are found in fine–to-medium–grained sands with fine-grained ore minerals, with a significant - up to 30% - content of ilmenite in the siltstone-clay fraction. The Satpayevskoye field of the Zaisan depression is characterized by similar dimensional parameters. The placers of the northern slope of the Kazakh Shield are characterized by fine-grained sand and ore minerals of coarse siltstone (0.1-0.05 mm), fine siltstone and clays (less than 0.05 mm).

Discussion

Sequence of processes of placer deposition and ore bodies facies diagnostic

Genetically, the placers of these provinces differ in their facies type:

- North Kazakhstan placers (Obukhov, Kara-Agash, Zayachya, etc.) are composed of Eocene fine-grained sands. Facies diagnostics [[1], [2]] indicate sublittoral formation conditions with a predominance of longshore accumulative sands in the lower part of the Obukhov sequence and a complex polyfacies sequence with the participation of deposits of longshore ridges, delta channels, bars, and embankments in the upper part of the Obukhov sequence. Clays of the false raft coincide with a short-term retreat of the sea, with the formation of a lagoon or delta in place of the open coast. The texture of the sands is mainly wavy, the series alternate with horizontally layered, formed by thin layers of rich sludge (1-3 cm), coarse sands or siltstones. Such features of the ore-bearing stratum indicate the absence of classical beach deposits, which are characteristic of modern placers of the oceanic coasts of Australia, India, South Africa, etc. [[1], [2], [37], [38]].

- Placers of the Pavlodar Irtysh region was formed in less active conditions of the sublittoral (off-shore placers). Fine-grained sands with fine (silty) ore minerals predominate, having an indistinctly stratified or weakly expressed wavy texture. Such formations are typical for delta islands, lagoon beaches, and, in general, coasts where water exchange with the open sea is difficult [[2], [10], [32], [38]]. The false raft is also considered, as in the placers of Northern Kazakhstan, as a product of short-term regression, but due to the beginning of the activation of the formations of the Chingiz-Tarbagatai zone, which was drained by watercourses supplying placer components to the Druzhby region, and the inherited deflection of the Irtysh syneclise, coarser-grained material was supplied to the coastal zone [2]. The actual sands of the false raft appear to be alluvial or alluvial-deltaic.

- Placers of the Zaisan region are polyfacies formations (deluvial-proluvial-alluvial, with the inclusion of eluvium of the primary source in the lower sections) (Kara-Otkel), or alluvial, which drained the rich primary source of ilmenite directly [[5], [6], [26], [29]]. The formation of the Kara-Otkel placer deposit is associated with the onset of rifting, which manifested itself in the subsidence of the Zaisan Basin and the renewal of the river network on its northwestern margin. In contrast, the topography of the Kara-Otkel-Preobrazhenskaya multiphase intrusive region, like that of the entire Rudny Altai, retains a weakly defined undulating character with a developed weathering crust throughout the Paleocene. The onset of peneplain destruction likely occurred during the Danian-Ypresian interval.

By the end of the Miocene, Altai was a medium-low mountain country, including the northwestern periphery of the Zaisan Depression [[15], [34], [39]]. This process directly influenced the formation of placers of the Satpayevsky deposit. Unlike the Kara-Otkiel basin, the reason is not rifting with the deflection of the Zaisan Depression, but the growth of mountains that began in the Early Miocene and peaked in the Early Quaternary [34]. The sediments of the lower part of the Aral formation correlate with the growth of the mountains. It is obvious that orogeny took place in a pulsating mode – the Lower Miocene stage took place, after which the Altai Mountain were leveled. The next was the lower Quaternary stage of large-scale mountain growth associated with the continuation of the collision of Hindustan and Asia, when there was a significant increase in the Himalayas, Kunlun, Pamir and the general uplift of Tibet [[39], [40], [41]].

The placers age estimation in Northern Kazakhstan and the Pavlodar Irtysh region is ambiguous due to the rare finds or uncertainty of any faunal or floristic remains in the placer strata.

Since the extensive exploration of Ti-Zr placers in northern Kazakhstan and southern Western Siberia (late 1950s – mid-1960s), the formation of coastal-marine placers has been considered to be of Middle Eocene – Lower or Middle Oligocene age, with reference to the coastal facies of the Tavda Formation. Some of this view remains valid today [[11], [22], [30]].

At the same time, in the late 1970s, V. A. Dargevich identified the first spore-pollen assemblages, allowing for a more precise age determination of the ore-bearing sands, as corresponding to the upper reaches of the Lyulinvor Formation, or the upper part of the Middle Eocene [[42]]. Subsequent work by the authors on assessing the rare-metal potential of Kazakhstan's placers confirmed these views [[2], [10], [32]], leading to a refinement of the geological and genetic position of the placers and, ultimately, to an increase in the prospects of the eastern part of Northern Kazakhstan, with a likely strengthening of the mineral resource base of the Republic of Kazakhstan for titanium, zirconium, and rare earth elements.

The placers framing the Kokshetau Proterozoic massif – Obukhovskaya group, Letovochnaya, Kara-Agash, and others - have been dated fairly reliably. The Obukhov formation (ob1-3) is compared with the middle-upper part of the Lyulinvor formation of Western Siberia, late Lutetian-Bartonian [[10], [22], [36]].

As for the placers of the Pavlodar-Irtysh region, the question of the age dating and the relationship of ore-bearing formations in the Pavlodar Irtysh region and Northern Kazakhstan remains controversial. The following should be noted:

1. The influx of huge masses of dissolved silicic acid and silica gel into the coastal waters of the Lyulinvor basin, with the simultaneous development of radiolariae, sponges, and diatoms in deeper parts of the sea. Well-known sections of the Lyulinvor in the valley of the Olenty River, at the confluence with the lake Auliekol are formed by chemo- and biogenic opoka [36].

2. A site of alluvial formations was identified by one of the authors 40 km south-east of the Druzhba placer, in an ancient river valley inherited by the modern Tundyk River. The section shows a gradual transition from the bottom up, from coarse-grained sands through gradual silicification to almost pure quartzite. The thickness of the sands is 3.5 m, sandstones, from loose to dense, on ferruginous-siliceous cement – 1.2 m, quartzite with a thickness of 0.1-0.15 m lies on top.

The entire complex lies in a local Paleozoic depression, which preserved the sands from erosion during the latestactivation. This section corresponds the formations of the false raft of the Druzhba placer due to the identity of the composition and dimension of the sands [[32], [36]].

3. It seems possible to assume epigenetic silicification of the sands and to draw a parallel with the time of accumulation of siliceous rocks in the middle part of the Lyulinvor formation of Western Siberia, respectively, the Tundyk alluvium is older than the placers of the North Kazakhstan, probably the late Ypres-early-middle Lutetian. In this case, the main ore horizon of the Druzhba placer, correlating with the upper Obukhov strata (ob3), can be dated as Early-Middle Lutet. With this interpretation, Druzhba looks like a slightly older placer, in comparison with the deposits of Northern Kazakhstan: Lutetian age of Druzhba versus late Lutetian - Bartonian age of the placers of Northern Kazakhstan.

The question of why ore formations are shown in lutetian sands is also controversial.

Below, we will consider our hypothesis about the occurrence of a special wind circulation in Central Asia at the end of the Iperlutetia, which contributed to high concentrations of heavy fraction in coastal accumulative forms.

The movement of sediments along the coast is the main factor in the classification of material by hydraulic size and the formation of placers in sublittoral conditions. [[1], [22], [32], [37]. The presence of steady winds is assumed to be a prerequisite for the formation of coastal placers. This does not negate the formation of classical beach placers (black sands), which are most common in modern conditions, but in most cases, examples of Eocene beach formations have not been reliably confirmed.

Since sublittoral placers themselves are indicators of the direction of coastal transport [[1], [32], [33], [38]] and are always located west of river deltas that served as the main suppliers of ore minerals, it would be logical to assume a northwesterly direction of coastal currents and, accordingly, a westerly or northwesterly direction of prevailing winds.

It is assumed [[31], [43]] that the high-pressure zone in Tarim has existed since the end of the Cretaceous period, and the high-pressure zone in the Gobi appeared with the onset of global cooling in the middle to the end of the Eocene. Due to the non-contrasting climate of Central Eurasia, until the middle of the Eocene, there were no conditions for the occurrence of strong winds [[28], [31], [44], [45]]. Starting from Lutet, with a general cooling, there is an expansion of high-pressure zones in Tarim and Gobi (Fig. 12). This is facilitated by the cessation of water exchange between the Tethys and the Arctic, which was carried out through the Turgai Strait and leveled the climatic conditions of Eurasia in the range of 35-55 degrees north latitude. [[35], [43], [46]].

At the same time, the structures of Altai and Dzungaria were shallow hills and hilly plains that did not interfere with the western winds [40]. On the

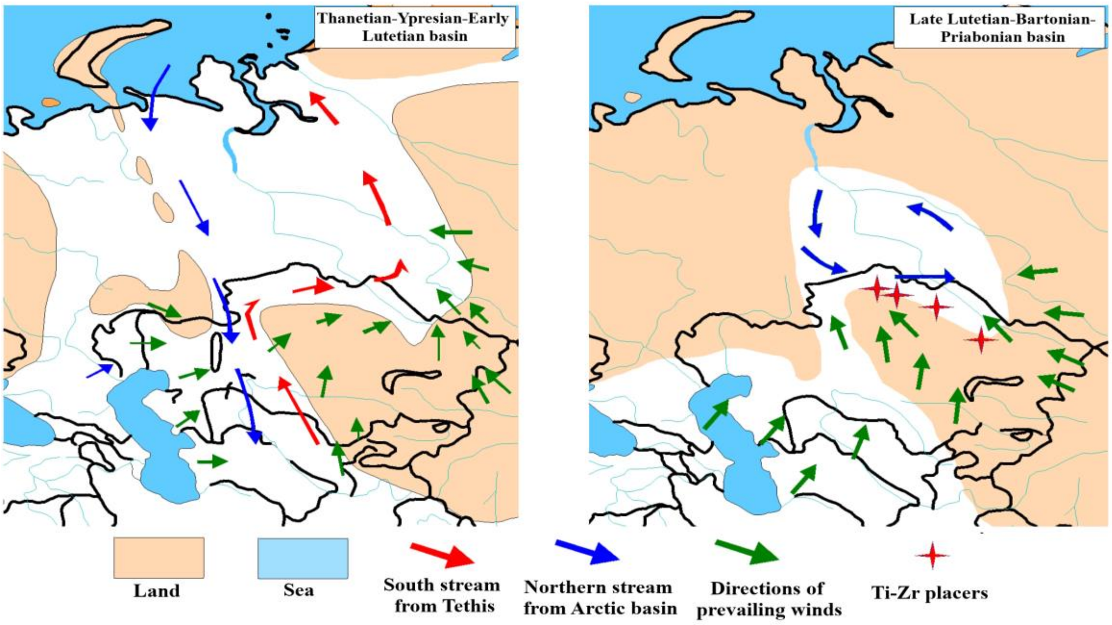


Figure 12 - Palaeogeographical scheme of the Central Eurasia for early Eocene (leftward) and mid- late Eocene (on the right), according to [[35], [46]]. Atmospheric circulation - author's views

other hand, the beginning of large-scale erosion of the weathering crust of the Kazakh shield contributed to the penetration of silica compounds into the adjacent regions of the West Siberian basin, which led to the formation of a Lulinvor formation, siliceous in composition (opoka, siliceous clays, quartz sand). In coastal and subtidal conditions, concentrations of a heavy fraction of industrial scale are formed during Lutet, which was facilitated by:

- deep chemical weathering of the primary sources of placers - formations of different ages forming the Kazakh shield, Dzungaria and Altai;
- the existence of river systems - ways of transferring ore minerals to final runoff basins,
- the emergence of a stable system of atmospheric circulation in the form of westerly and northwesterly winds, which led to constant coastal currents in the West Sobir Sea and, in turn, to the formation of various coastal accumulative forms containing increased concentrations of heavy fraction, which became the basis for the formation of placers. The formation of beach placers proper most likely took place, but the vast majority of them were destroyed by subsequent erosion.

The above reasons for the generation of industrial accumulations of the heavy fraction expand the prospects for the discovery of new titanium-zirconium placers in the Pavlodar Irtysh region. The results of paleogeographic reconstructions given in this article, as well as in other works of the authors [[1], [2], [32], [38]], suggest that new placer ore bodies can be found south of the placer mining belt, which extends more than 400 km along on the northern slope of the Kazakh shield and in the Pavlodar Irtysh region.

We believe that the formation of ore bodies in the main (upper) ore horizon of the Druzhba placer does not correspond to the maximum transgression level of the Ipresian-Lutetian basin, but rather indicates stabilization.

The deepest penetration of the sea into the Kazakhstan shield is shown by blue boundary on (fig 3) and marked by fields of medium- and coarse-grained sands covered by quartzites. It dated by the Eocene on geological maps, more precisely, in our opinion, by the early Lutetian. These formations are widespread from the valley of the Shiderta River in the west to the valley of the Tundyk River in the east, forming separate sand lenses up to 3-10 km long and 1-2 km wide, preserved from subsequent denudation in the depressions of the Paleozoic basement.

In some of these areas, quartzite-like sandstones lie directly on Paleozoic complexes; in others, sands up to 10-12 meters thick lie between sandstones and Paleozoic rocks, and reveal increased contents of heavy minerals up to 10-12 kg per ton [32]. From our point of view, such formations can be the remains of beach placers of Eocene basins [2]. In addition, east of the Bestau Mountains, within the western slope of the Irtysh syneclise, sands correlating with the lower ore layer of the Druzhba placer are possible. These sands are traced by single wells at a depth of 10-50 meters and are covered by Pliocene clays and Quaternary sands. The above considerations significantly expand the prospects for the discovery of titanium-zirconium placers along the eastern part of the northern slope of the Kazakh Shield.

Conclusion

In preparing this article, the authors sought not only to describe individual objects of the placer series of formations in the series "weathering crust - alluvial placer - coastal-basin placer", but also to show the features of the processes of placer genesis for each of the members of this series, both locally and regionally. In particular, this applies to Ti-Zr placers of the Zaysan depression, Northern Kazakhstan and Pavlodar Irtysh region, the subject of authors's many years research.

The issue of correlation of Northern Kazakhstan single coastal-marine formation with classical marine formations of Western Siberia - the Lyulinvor and Tavda formations of the Eocene is considered. The older age of the Obukhov stratum for the Pavlodar Irtysh region is being substantiated in comparison with the northern slope of the Kazakh shield.

For the first time, we consider the factor of regional atmospheric circulation as one of the decisive for the formation of the Eocene placer-bearing coastal-marine formation. The sequence of tectonic-climatic changes in the Late Cretaceous-Eocene of Central Asia is substantiated as the reason for the subsequent placer formation.

The chain of events originates in the collision of the Indian subcontinent and Eurasia, which was reflected in Northern Kazakhstan by a complex of block movements and the beginning of a large-scale erosion of eluvium formed during the Dat-Eocene climatic optimum. At the same time, there is a shallowing of the Turgai Strait with the cessation of communication between the Arctic and Tethys basins. The result is an increase in climate contrast, with the activation of intracontinental high-pressure zones in Tarim and Gobi, with the emergence of a system of stable westerly and northwesterly winds. We believe that such climatic events led to the generation of constant alongshore currents, which became the main agent of coastal placer generation in the Middle, and to a lesser extent in the Late Eocene. At the same time, classic beach placers could form, but, most likely, were destroyed by subsequent denudation, and their finds are not reliably known.

This interpretation of the tectonic and climatic events of the Early Paleogene explains the location of placers on the northern slope of the Kazakh Shield and in the Pavlodar Irtysh region. Placers are always located to the west of the paleodeltas, which determines the leading role of rivers in the supply of ore material, unlike modern coastal-marine placers, where the main role in the ore material suppling belongs to coastal abrasion.

At the same time, prospects are expanding for the discovery of new ore placer deposits south of the border of Paleogene deposits continuous distribution at Northern Kazakhstan and Pavlodar Irtysh region. We believe that there is reason to expect the discovery of beach and delta placers in the depressions of the Paleozoic basement, made by Eocene sands and armored quartzite-like sandstones.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

CRediT author statement: **I.Poezzhaev:** supervision, conceptualization, investigation, writing-original draft; **D.Nigmatov** and **M. Imangalieva:** writing -original draft, writing -review & editing, supervision; **O. Gavrilenko, N. Temirbekov, Z.Mustafina, N. Zimanovskaya:** conceptualization, writing -review & editing.

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Data availability statement: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Солтүстік және Шығыс Қазақстан Кайнозойындағы шашылымдардың түзілу процестері

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ТҮЙІНДЕМЕ
Мақала Шығыс және Солтүстік Қазақстан аумағындағы шашылымдардың түзілуінің толық геологиялық-генетикалық қатары бойынша деректерді жалпылауға арналған. Онда Au, Ni, Co, RM, Ti, Zr, Nb, TR кен минералдарының түпкі көздерінде қалыптасқан каолиндік профильдегі үгілу қыртыстарынан бастап, Зайсан ойысындағы жақын тасымалданған полифациялық және аллювиалдық шашылымдар арқылы Солтүстік Қазақстан мен Павлодар Ертіс маңының жағалау-теңіздік ильменит-цирконды шашылымдарына дейінгі түзілу кезеңдері қарастырылады. Рудный Алтайдағы алтын және никельге бай үгілу қыртыстарының қималары мен кендердің локализация заңдылықтары неғұрлым егжей-тегжейлі талданған. Тектоникалық режимнің ерекшеліктеріне байланысты Зайсан ойысындағы палеоцен–миоцен кезеңіндегі ильменит шашылымдарының қалыптасу жағдайлары сипатталады: палеоцен–эоцендегі рифтогенез және төменгі миоцендегі орогенез. Қазақ қалқанының элювийінен кремнийдің ауқымды шайылуына байланысты Павлодар Ертіс маңы шашылымдарының жасы нақтыланған. Жағалау-теңіздік шашылым түзілу процестерінің Орталық Еуразиядағы аймақтық палеогеографиялық өзгерістермен байланысы көрсетілген. Бұл өзгерістер Индостан мен Еуразия плиталарының соқтығысуынан және палеоцен–төменгі эоцен кезеңіндегі температуралық максимумнан бастау алады. Сонымен қатар Тетис пен Арктика шельфтік теңіздері арасындағы су алмасудың тоқтауы нәтижесінде Тарим мен Гоби аймақтарынан батыс бағыттағы тұрақты желдердің қалыптасуы және олардың Қазақ қалқанының солтүстік шетінде сублиторальдық шашылымдардың түзілуіне ықпалы көрсетілген.

Түйін сөздер: Үгілу қыртысы, титан, сирек металдар, жағалау-теңіздік шашылымдар.

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Процессы Россыпеобразования в Кайнозое Северного и Восточного Казахстана

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АННОТАЦИЯ
Статья посвящена обобщению данных по всему геолого-генетическому ряду россыпегенеза в Восточном и Северном Казахстане: от образования кор выветривания каолинового профиля на коренных источниках рудных минералов Au, Ni, Co, RM, Ti, Zr, Nb, TR, через полифациальные и аллювиальные россыпи ближнего сноса Зайсанской впадины до прибрежно-морских ильменит-цирконовых россыпей Северного Казахстана и Павлодарского Прииртышья. Более подробно рассмотрены разрезы и закономерности локализации руд для золота- и никеленосных кор выветривания Рудного Алтая. Дано представление о различных обстановках формирования палеоцен-миоценовых ильменитовых россыпей Зайсанской впадины, в зависимости от тектонического режима – рифтогенеза в палеоцен-эоцене и орогенеза в нижнем миоцене. Уточнена датировка россыпей Павлодарского Прииртышья, в связи с масштабным выносом кремния из элювия Казахского щита. Показана связь процессов прибрежно-морского россыпегенеза с региональными палеогеографическими изменениями в Центральной Евразии, начиная с коллизии Индостана и Евразии и палеоцен-нижнеэоценового температурного максимума. Показана роль завершения водообмена между шельфовыми морями Тетиса и Арктики в возникновении постоянных ветров западного направления из Тарима и Гоби в возникновении сублиторальных россыпей северного обрамления Казахского щита.

Ключевые слова: Кора выветривания, титан, редкие металлы, прибрежные россыпи.

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